ONE-SIDE-ELECTRODE-TYPE FLUIDIC SENSING MECHANISM INSPIRED FROM FISH CUPULA

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ONE-SIDE-ELECTRODE-TYPE FLUIDIC SENSING MECHANISM INSPIRED FROM FISH CUPULA

by

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LIST OF ABBREVIATIONS

ADC	-	Analog to Digital Converter
APDL	-	Ansys Parametric Design Language
AUV	-	Autonomous Underwater Vehicle
Al	-	Aluminium
Au	-	Aurum/Gold
CAD	-	Computer-Aided Design
CB	-	Carbon Black
CFD	-	Computational Fluid Dynamic
Cr	-	Chromium
DOF	-	Degree Of Freedom
DMF	-	Dimethylformamide
EDLC	-	Electrical Double Layer Capacitor
EDM	-	Electric Discharge Machining
FEA	-	Finite Element Analysis
FSR	-	Force Sensitive Resistor
FR-4	-	Flame Retardant 4
INA	-	Instrumentation Amplifier
LCP	-	Liquid Crystal Polymer
LF	-	Low Frequency
LPCVD	-	Low-Pressure Chemical Vapour Deposition
MEMS	-	Micro-Electro-Mechanical Systems
MWNT	-	Multi-Walled Nanotubes
PEG	-	Polyethylene Glycol

PCB	-	Printed Circuit Board
PDMA	-	Plastic Deformation Magnetic Assembly
PDMS	-	Polydimethylsiloxane
PI	-	Polyimide
PU	-	Polyurethane
PVDF	-	Polyvinylidene Fluoride
PZT	-	lead Zirconium Titanate
RIE	-	Reactive-Ion Etching
RP	-	Rapid Prototype
SEM	-	Scanning Electron Microscope
Si	-	Silicon
UV	-	Ultraviolet

LIST OF SYMBOLS

A_s	-	Surface area of electrode
A_h	-	Surface area of hair cell
A_+	-	Surface area of sensing electrode
C_o	-	Common capacitance
C_+	-	Sensing capacitance
C_U	-	Capacitance change for pressure up
C_P	-	Capacitance change for pressure down
C_T	-	Total capacitance
C_D	-	Drag coefficient
D	-	Hydraulic diameter
d	-	Thickness of insulator
E	-	Young’s Modulus
E_o	-	Bridge voltage
F_d	-	Drag force of hair cell
F_y	-	Drag force along vertical distance
F_{ym}	-	Vertical force for membrane
G	-	Gauge factor of strain gauge
I	-	Moment of inertia
L	-	Microchannel length
l	-	Length of hair cell
l_+	-	Length of sensing electrode
M	-	Moment of hair cell
p	-	Pressure of fluid

P	-	Pressure applied to the membrane
P_U	-	Pressure up
P_D	-	Pressure down
r_+	-	Radius of sensing electrode
R_e	-	Reynold number
R_m	-	Radius of membrane
t	-	Thickness of hair cell
t_m	-	Thickness of membrane
t_c	-	Thickness of microchannel
u_y	-	Velocity along vertical distance
u_o	-	Applied flow rate
v	-	Fluid velocity
V_{avg}	-	Average flow velocity
V_{amp}	-	Amplifier voltage
V_{ref}	-	Reference voltage
$V_{membrane}$	-	Volume deflect by membrane
V_{liquid}	-	Volume deflect by liquid
w	-	Width of microchannel
w_+	-	Width of sensing electrode
W	-	Deflection of membrane
x	-	Leading edge distance
y	-	Vertical distance
μ	-	Dynamic viscosity
ΔC	-	Capacitance changes
ΔL	-	Liquid displacement

ΔP	-	Pressure difference
ρ	-	Density of water/fluid density
δ	-	Boundary layer thickness
ε	-	Strain estimation on hair cell
ε_o	-	Vacuum permittivity
ε_r	-	Dielectric constant of PDMS
η	-	Viscosity
υ	-	Poisson's ratio

MEKANISMA PENDERIAAN BENDALIR JENIS-ELEKTROD-SATU-SISI DIINSPIRASIKAN DARIPADA KUPULA IKAN

ABSTRAK

Penambahbaikan reka bentuk penderia berasaskan silikon direalisasikan dengan teknik fabrikasi kompleks yang mungkin mengurangkan keteguhan dan kebolehpercayaan penderia. Selain itu, kebanyakan penderia aliran semasa hanya mampu mengukur aliran dalam satu arah dan memerlukan lebih daripada satu penderia untuk meningkatkan keupayaan terutamanya untuk penderiaan pelbagai arah. Masalah-masalah ini boleh ditambah baik dengan menggunakan sistem bendalir untuk pengukuran aliran bawah air yang diinspirasikan daripada mekanisma kupula pada badan ikan. Kupula menjadi pengantara daya-daya seretan dalam suasana sekeliling dan memindahkan pergerakan kepada sel-sel rambut untuk mendorong isyarat sel saraf. Reka bentuk penderia aliran yang dicadangkan dalam kajian ini terdiri daripada elektrod-satu-sisi dan membran berbentuk kubah yang diintegrasi dengan saluran mikro. Apabila aliran mengenai membran, ia memberikan pesongan dan menganjak elektrolit di dalam saluran mikro. Elektrod, melalui lapisan penebat mengesan pergerakan elektrolit dan memberi perubahan dalam kemuatan. Dalam peringkat reka bentuk, simulasi telah dimulakan dengan memilih tiga jenis struktur termasuk bentuk segi empat tepat dan silinder sel rambut dan juga bentuk kubah. Struktur kubah didapati lebih sesuai untuk penderiaan pelbagai arah kerana struktur simetri yang membenarkan daya seretan yang tetap dari arah yang berbeza. Parameter membran berbentuk kubah seperti dimensi dan bahan-bahan telah diubah dan disimulasi. Disebabkan oleh mekanisma penderiaan baru, penderia tekanan yang mempunyai membran rata telah difabrikasi sebagai ujian awal. Kedua-dua membran berbentuk kubah dan membran rata telah difabrikasi menggunakan proses litografi lembut.

Kemudian, penderia tekanan berasaskan bendalir telah dicirikan berdasarkan kesan getaran dan suhu. Ujian kebolehpercayaan penderia tekanan untuk getaran dan suhu telah menunjukkan ralat pengukuran penderia ialah 3% oleh getaran lebih 25 Hz pada pecutan ± 2G dan 4%, untuk julat suhu daripada 10 hingga 50^{o}C. Untuk pencirian penderia aliran berasaskan bendalir, frekuensi operasi dan masa tindak balas masing-masing adalah 1.2 kHz dan 0.35 s. Penderia ini dapat mengukur kadar aliran serendah 10 cm/s di dalam air, dengan resolusi 5 cm/s. Ujian berarahan menunjukkan bahawa penderia itu mampu untuk mengesan aliran dalam pelbagai arah dan sudut yang berbeza, di samping dapat mengesan objek bergerak pada jarak dekat.

ONE-SIDE-ELECTRODE-TYPE FLUIDIC SENSING MECHANISM INSPIRED FROM FISH CUPULA

ABSTRACT

Enhancement of silicon-based sensor designs is often realized using complex fabrication techniques which may reduce the robustness and reliability of the sensor. Also, most current flow sensors are only capable of measuring in one direction, requiring more than one sensor to improve capability, especially for multidirectional sensing. These problems may be enhanced using a fluidic system for underwater flow measurement, as inspired from the cupula mechanism on fish bodies. A cupula mediates the drags forces in the surrounding environment and transfers the movements into hair cells to induce the neuron signals. The proposed flow sensor design in this research consists of a one-side-electrode and dome-shaped membrane integrated with a microchannel. When the flow hits the membrane, it provides deflection and displaces the electrolyte inside the microchannel. The electrode, via its insulator layer senses the movement of the electrolyte and gives a change in capacitance value. During the design stage, the simulation was started by selecting three types of structure, including rectangular and cylinder shape of hair cell and also the dome-shaped. The dome structure has been found to be more suitable for multidirectional sensing due to its symmetry structure, which allows the constant drag force from different directions. Dome-shaped membrane parameters such as dimension and materials were varied and simulated. Due to the new sensing mechanism, the pressure sensor that has flat membrane was fabricated as a preliminary test. Both a dome-shaped membrane and flat membrane were fabricated using the soft lithography process. Then, a fluidic based pressure sensor was characterized based on vibration and temperature effect. A reliability test for the

pressure sensor for vibration and temperature has demonstrated that the sensor measurement error was 3% by vibration over 25 Hz at acceleration ±2G and 4%, for a temperature range from 10 to 50^{o}C. For the fluidic based flow sensor characterization, operating frequency and time response were 1.2 kHz and 0.35 s, respectively. This sensor was able to measure the flow rate at rates as low as 10 cm/s in water, with a resolution of 5 cm/s. The directionality test has shown that the sensor is capable of detecting flow in different direction and angle, while also being able to detect a moving object at close range.